RESEARCH DEPARTMENT

A F.M. RECEIVER INCORPORATING A NEW TYPE OF LIMITER AND DISCRIMINATOR

Report No. G-076

(1959/24)

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

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December 1959

Report No. G-076

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A F.M. RECEIVER INCORPORATING A NEW TYPE OF LIMITER AND DISCRIMINATOR

SUMMARY

This report describes a f.m. receiver, covering the band 87·5 to 100 Mc/s, which incorporates a recently developed limiter and discriminator circuit. While comparable in cost and complexity with the simpler type of domestic receiver which relies on a ratio detector for amplitude limiting, it provides a higher degree of amplitude-modulation suppression than such receivers generally attain.

1. INTRODUCTION

In an ideal f.m. receiver, changes of amplitude of the input signal should produce no response at the output; while this condition cannot be achieved in practice, adequate suppression of amplitude modulation is essential if the performance of the receiver is to be satisfactory. In particular, a signal received in conditions of multipath propagation contains both a.m. and f.m. components of distortion; if the former is adequately suppressed the total distortion is considerably reduced[1] and for this purpose an a.m. suppression ratio of some 35 dB is required.*

The simpler types of domestic f.m. receivers usually rely for their a.m. suppression on a ratio detector unassisted, at least over the lower range of input levels, by any other form of limiting. The a.m. suppression ratio achieved is seldom as high as 35 dB and is often considerably lower, with the result that the performance, while satisfactory under most conditions, can be poor in the presence of multipath propagation.

The receiver described in this report incorporates a recently developed limiter and discriminator circuit[2,3] and, while it is comparable in cost and complexity with the simpler types of ratio detector receiver, it achieves better a.m. suppression characteristics without either requiring increased amplifier gain or sacrificing sensitivity.

* The a.m. suppression ratio of a receiver is defined, for the purpose of this report, in Section 3.6.

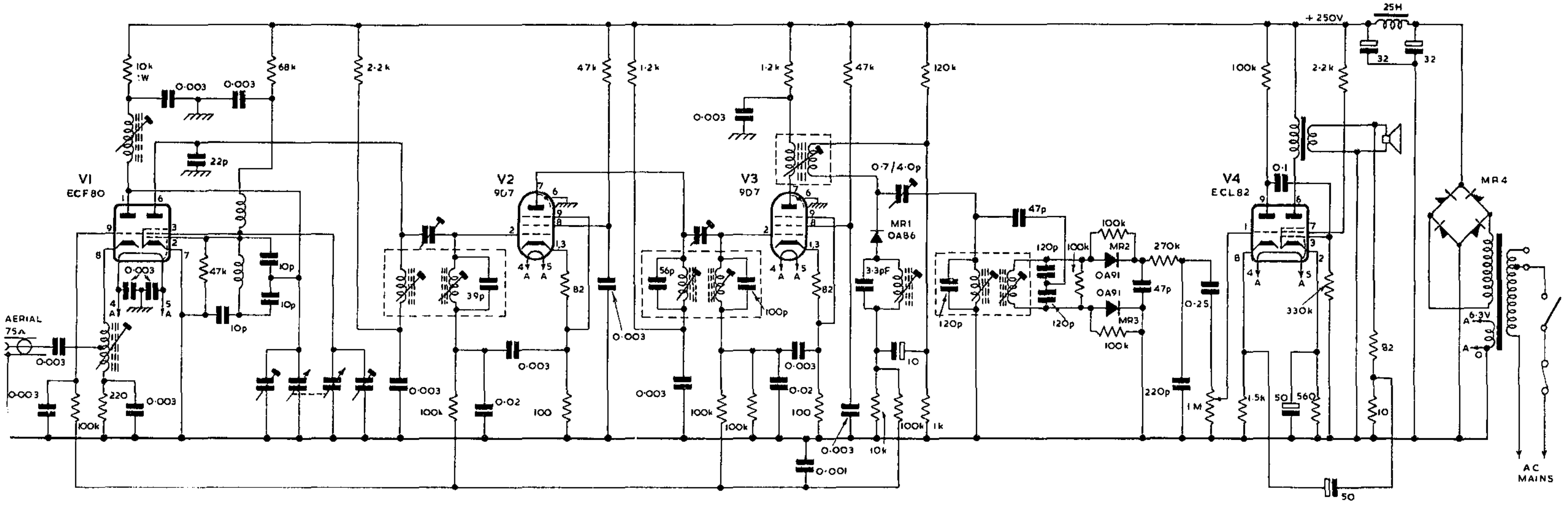


Fig. 1 - Circuit Diagram

2. CIRCUIT DESIGN

2.1. General

The circuit diagram of the receiver is shown in Fig. 1.

Apart from the limiter and discriminator the design differs little from established practice; V_1 is an ECF80 triode-pentode, the triode section operating as a grounded-grid r.f. amplifier and the pentode section as a self-oscillating mixer. V_2 and V_3 are two 9D7 i.f. amplifiers; part of the cathode bias resistor of each stage is undecoupled to compensate for changes of input capacitance with variations of a.g.c. bias voltage.

The intermediate frequency is 10·7 Mc/s and the local oscillator frequency is below that of the signal. Three germanium diodes, one type OA86 and two type OA91, are used in the limiter and discriminator circuit; V_4, an ECL82 triode-pentode, is the audio-frequency amplifier and output stage.

2.2. The Limiter and Discriminator

The theory of the limiter and discriminator used has been dealt with fully elsewhere,[2] but can be summarized as follows.

Amplitude limiting devices are generally voltage operated and require input levels of one volt or so for satisfactory operation. Such levels do not normally occur in stages before the discriminator unless extra amplification is introduced specifically to drive a limiter. The required voltage, however, is normally available at the discriminator transformer itself and, if limiting can be performed there, the extra amplification is not needed. Although the ratio detector answers this requirement, its effectiveness is restricted because the functions of limiting and frequency-to-amplitude conversion are interdependent.

In the design of the Foster-Seeley discriminator it is assumed that it is fed from a high impedance source, i.e. one approximating to a constant-current generator, and the amplitude/frequency response of the transformer is utilized to control the linearity of the transfer characteristic. Thus, limiting of either the primary or secondary voltage or of a combination thereof would be unsatisfactory. The circuit proposed to overcome these limitations is shown in Fig. 2. In this circuit L_2C_2 and L_3C_3 are the primary and secondary circuits, respectively, of a conventional phase discriminator; L_1C_1 is a parallel resonant circuit across which is connected a

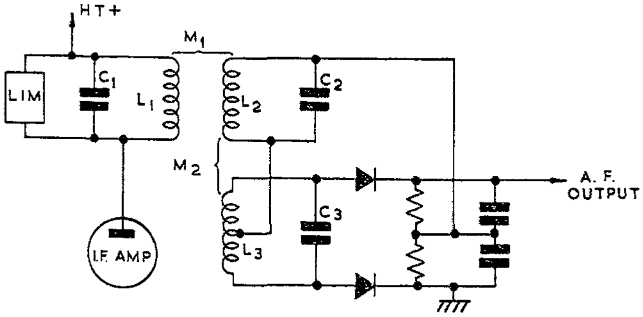
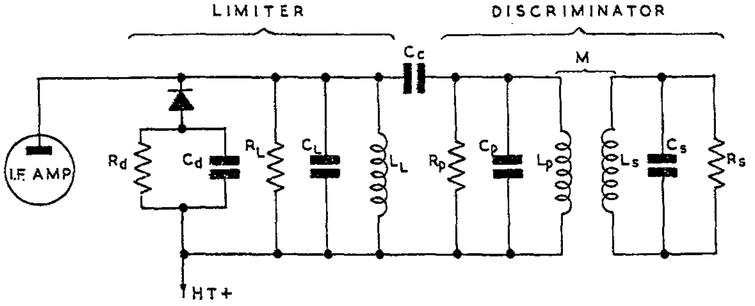


Fig. 2 - Basic limiter and discriminator circuit

voltage limiting device. The presence of this limiter makes the shunt impedance across L_1C_1 very low but, if L_1 be loosely coupled to L_2, the coupling acts as an impedance inverter and the discriminator is effectively fed from a high impedance source. Thus, although limiting is carried out at the voltage level of the discriminator, the two functions are independent and the presence of the limiter imposes no restrictions on the design of the discriminator.

The limiting device could take any one of several forms; one possibility is a biased diode which conducts when the peak i.f. voltage across L_1 exceeds the bias threshold. The limiter used here is based on the dynamic diode.[4] It employs a diode in series with a load consisting of a resistor and capacitor in parallel, the time constant of the combination being longer than the period of the lowest audible frequency. With this arrangement, amplitude changes with a period shorter than the time constant are suppressed by variation of the loading on the limiter tuned circuit. When the signal increases in amplitude the diode load voltage cannot change, so the diode current increases very sharply, with a resultant increase in the loading. Conversely, when the signal decreases in amplitude the diode tends to cut off, thus reducing the loading. One disadvantage of this type of limiter is that it gives no protection against slow amplitude changes whose period is long compared with the diode load time-constant; the load voltage follows the signal amplitude and the loading imposed by the diode circuit is constant. This limitation has been overcome in the receiver described by using the voltage across the limiter diode load for automatic gain control.

The practical design of the limiter can best be considered with reference to Fig. 3. The following symbols will be used; the remaining symbols given in Fig. 3 are self-explanatory:



$$Q_p = \frac{R_p}{\omega_o L_p}$$

$$Q_s = \frac{R_s}{\omega_o L_s}$$

$$k = \frac{M}{\sqrt{L_p L_s}}$$

$$Q = \sqrt{Q_p Q_s}$$

Fig. 3 - Equivalent circuit of limiter and discriminator

R_p = Total shunt losses of discriminator primary, including discriminator diode loading

R_s = Total shunt losses of discriminator secondary, including discriminator diode loading

R_L = Total shunt losses of limiter tuned circuit, excluding loading due to limiter diode

ω_o = $2\pi f_o$ where f_o is the intermediate frequency

At the mid-band frequency the input impedance of the discriminator, i.e. the circuit to the right of C_c, is

$$R_p' = \frac{R_p}{1+(kQ)^2}$$

The shunt impedance reflected into the limiter circuit at mid-band is therefore

$$R_o = \frac{X_c^{\,2}}{R_p'}$$

where $X_c = 1/\omega_0 C_c$. The resulting shunt impedance across which the limiter operates is

$$R_L' = \frac{R_L \cdot R_o}{R_L + R_o}$$

If we assume a rectification efficiency of 100% in the diode limiter, the effective shunt loading of the limiter circuit by the diode, with a constant amplitude input, is $R_d/2$. The ability of the limiter to cope with upwards modulation is virtually unlimited, but the maximum downwards modulation which can be dealt with is determined by the ratio between R_L' and $R_d/2$. In order to deal with a fractional depth of modulation m, we require that

$$R_L' \geqslant \tfrac{1}{2}R_d \cdot \frac{m}{1-m}$$

If this condition is not fulfilled the limiter diode will cut off in the troughs of amplitude modulation and the input to the discriminator will not be stabilized over that part of the modulation cycle. It should be noted that when this occurs the discriminator diodes continue to function, in contrast to the ratio detector in which, if the maximum possible modulation depth is exceeded, the discriminator diodes are cut off over part of the modulation cycle.

Taking as typical values $R_d = 10\ k\Omega$, $R_L = 50\ k\Omega$, $R_p' = 2\ k\Omega$, $f_o = 10{\cdot}7$ Mc/s, it follows that to achieve satisfactory amplitude modulation suppression for values of m up to 0·8, requires C_c to be 1·83 pF. The impedance reflected across the discriminator primary from the limiter circuit is X_c^2/R_x where R_x is the effective dynamic impedance of the limiter and its load. Measurements indicate that R_x is about 500 Ω, so that with the conditions specified $X_c^2/R_x \simeq 130\ k\Omega$. This is sufficiently high, compared with R_p, to be negligible. As C_c is reduced, the downwards amplitude modulation depth which can be dealt with is increased, but the discriminator slope is reduced; this parameter is therefore a compromise between overall gain and the depth of modulation that can be handled.

The limiter in the form shown in Fig. 3, with an OA86 crystal diode, gives an a.m. suppression ratio of some 30-35 dB; but if a parallel tuned circuit, resonant at the frequency of the third harmonic of the i.f., be inserted in series with the limiter diode, a further increase in limiting efficiency is obtained. The action of this harmonic filter is to modify the shape of the current pulses through the diode in such a way that its effective dynamic impedance is reduced.

The limiter circuit actually embodied in the receiver differs from Fig. 3 in three respects:

(i) The third harmonic filter is included.

(ii) The limiter circuit inductor is wound as a close-coupled transformer; this isolates the limiter from the h.t. line and permits the limiter load to be earthed, thus simplifying the provision of an a.g.c. voltage.

(iii) A delay voltage is applied to the diode to improve the a.g.c. characteristic and hence the suppression of slow amplitude fluctuations.

Dynamic input/output curves of the limiter as used in the receiver, for r.f. input levels of 30 μV, 100 μV and 1 mV are given in Fig. 4, together with the 1 mV curve of the basic limiter without the third harmonic filter. All curves are normalized to the same operating point and the effective reduction of amplitude modulation by the limiter is shown by the ratio of the slope of the dynamic curve to that of the line passing through the origin and the operating point. These curves also demonstrate the reduced capacity to handle downwards modulation at low signal input levels; this is due partly to the delay voltage applied to the limiter, and partly to the rise in the impedance of the diode at low currents.

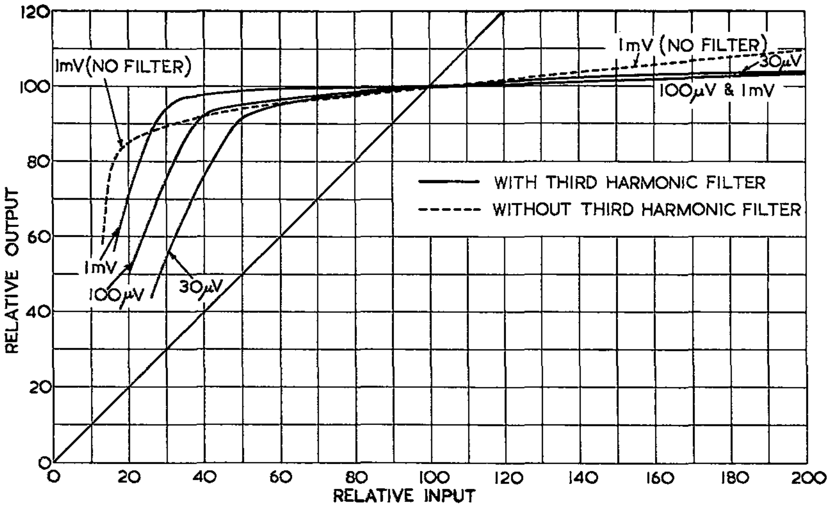


Fig. 4 - Dynamic limiter characteristic

2.3. Construction and Alignment of Limiter and Discriminator

Details of the construction of the coils in the limiter and discriminator circuits are given below. In all cases the cores used were Neosid Grade 900, Type 6 × 1 × 12.

Limiter Transformer:	Neosid Type 5000A/6E former (7·6 mm dia). Two single layer solenoids, each 50 turns 38 s.w.g. enamelled wire, close wound, one over the other and separated by one layer of cellulose tape. The external connections are arranged so that the low i.f. potential ends of the two windings are adjacent.
Third Harmonic Filter:	Neosid Type 3500 former (7 mm dia.). 25 turns 38 s.w.g. enamelled wire close wound.
Discriminator Transformer:	Neosid Type 5000 B/6E former (7·6 mm dia.). Primary*:* 15 turns 30 s.w.g. enamelled wire wound with 1/1 space ratio. Secondary*:* 20 turns 30 s.w.g. enamelled wire close wound.

Alignment of a limiter and discriminator of this type is most conveniently carried out in two stages. First, the third harmonic filter is short-circuited and the limiter transformer tuned to the intermediate frequency by adjusting for the maximum d.c. voltage across the limiter load. The discriminator can then be aligned in the usual way. An oscilloscope display of the limiter input/output curve should next be set up, as shown in Fig. 5. The receiver is fed with a 100% amplitude-modulated signal and the Y input of the oscilloscope is connected through a suitable "hold-off" resistor to one side of the discriminator transformer secondary, thus using one discriminator diode as an a.m. detector. The X input to the oscilloscope is obtained from the signal-generator-modulating voltage. This will produce on the oscilloscope a limiter curve similar to those shown in Fig. 4. The short circuit is now removed from the third harmonic filter and the final adjustment of the limiter transformer tuning, harmonic-circuit tuning and limiter/discriminator coupling made. The limiter transformer is tuned to obtain the maximum downwards limiting, the value attainable being determined by the limiter/discriminator coupling capacitance. The harmonic filter is tuned principally for maximum flatness of the top of the curve, that is, maximum a.m. suppression, but also to ensure maximum downward limiting. Thus it will be found that as the tuning inductance is increased from the optimum

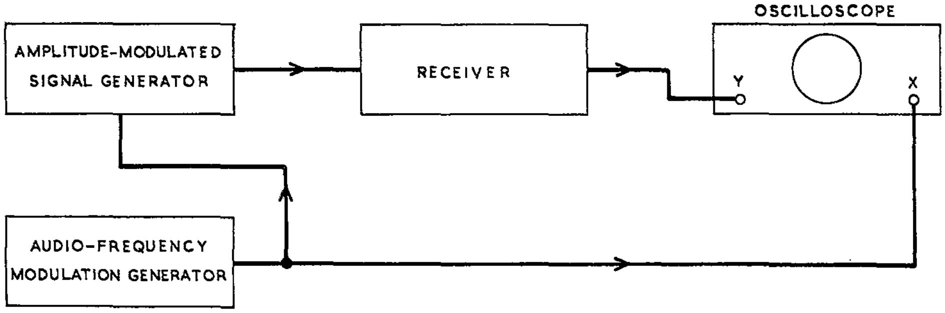

OSCILLOSCOPE
AMPLITUDE-MODULATED SIGNAL GENERATOR
RECEIVER
Y
X
AUDIO-FREQUENCY MODULATION GENERATOR

Fig. 5 - Method of displaying limiter characteristic

value, the flat top of the dynamic curve begins to tilt, while if the inductance is reduced, the downward limiting threshold is raised. The adjustment is not unduly critical; a variation of some +20% - 10% of inductance from the optimum could be tolerated in the prototype receiver without serious impairment of the limiter performance. Gross mis-tuning, however, causes a considerable deterioration; the effect of an increase of inductance of 80% above the optimum value is shown in Fig. 6.

Having set up the limiter, the discriminator tuning should be checked to complete the alignment.

2.4. Tuning

One difficulty in tuning a f.m. receiver is to distinguish between the side responses and the central response of the discriminator. If no tuning indicator is fitted it is essential, in order to avoid confusion, that these side responses be either sufficiently low in amplitude or be recognizable by their poor signal-to-noise ratio. Curve (a) of Fig. 7 gives the tuning characteristic of the receiver with an input signal of 1 mV, frequency modulated to ± 30 kc/s. If better suppression of the

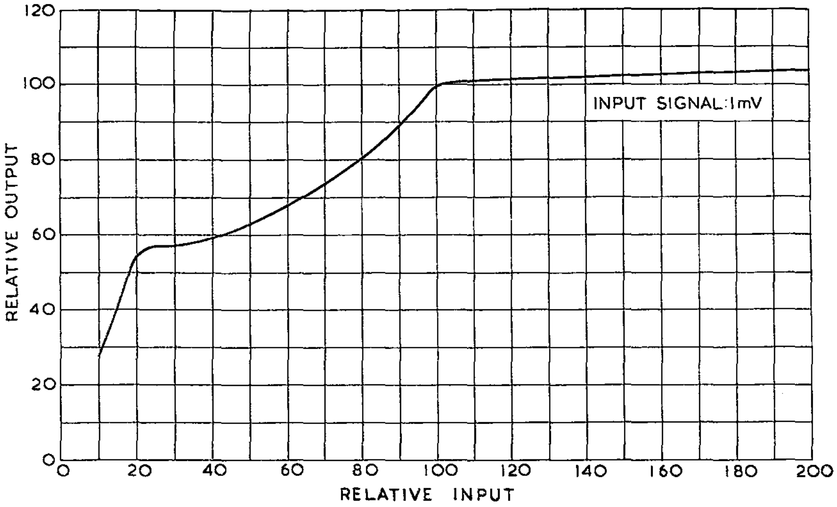


Fig. 6 - Dynamic limiter characteristic with mis-tuned harmonic filter

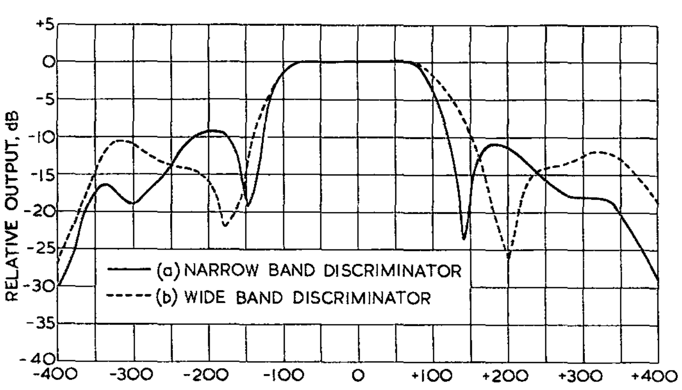


Fig. 7 - Tuning characteristic

side responses is required, it may be obtained by increasing the discriminator bandwidth, and curve (b) shows the performance under the same input conditions with a discriminator having a peak separation of ±200 kc/s. The use of the wider discriminator entails a reduction of about 3 dB in adjacent channel suppression and some loss of gain, but this may be thought justifiable for greater ease of tuning. A difficulty that remains, however, is that of obtaining the best tuning position within the central response.

Another approach to the problem of simplifying tuning is to provide some kind of indicating device, preferably one which shows the centre point of the discriminator and is unaffected by the shape of the i.f. amplifier response.

With the normal phase-discriminator circuit the outputs of the two diodes are combined in such a way that a null point indicator is required. It is possible, however, by making minor modifications to the circuit, to obtain a d.c. output from the discriminator which is suitable for operating a conventional "magic eye" tuning indicator. These modifications, shown in Fig. 8, involve the addition of three resistors, R_a, R_b and R_c, and two capacitors, C_a and C_b. The discriminator secondary circuit is now earthed to modulation frequencies by the capacitor C_a, but the d.c. earth is at the junction of R_a and R_b, with the result that a voltage equal to the mean of the rectified voltages across the two diode loads appears at the junction of R_c and C_b. The variation of this voltage with carrier frequency is shown in Fig. 9. The dip in the middle of the curve provides a precise indication of the centre of the discriminator response; since the discriminator is outside the a.g.c. loop, while any variations in the i.f. amplifier response are compressed by the action of a.g.c., the accuracy of the indication is not greatly impaired by asymmetry of the i.f. response.

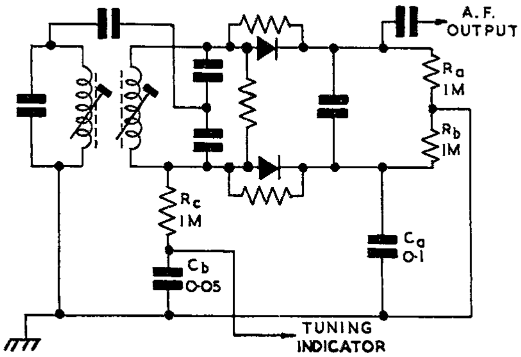


Fig. 8 - Circuit modifications to obtain tuning indicator drive from discriminator

The disadvantage of this system is that it requires the user to adopt an unusual criterion in reading the tuning indicator. This can be overcome, at some sacrifice of accuracy, if the circuit is re-arranged as shown in Fig. 10, with the lower end of the resistor R_c connected to the negative end of the limiter diode load, and the tuning indicator voltage obtained from the junction of R_a and R_b. With this arrangement the indicator is operated by the difference between the a.g.c. voltage and the mean discriminator voltage. The shape of the resultant curve is shown in Fig. 11; for comparison the curve of the a.g.c. voltage alone is also shown, normalized to the same amplitude at the tuning point.

3. TEST RESULTS

The receiver was tested in accordance with the specification contained in a Research Department technical memorandum,[5] with some additional tests. It should be noted that all ratios of signal to noise, hum or interference quoted were measured with a mean-square meter preceded by an aural sensitivity weighting network based on the C.C.I.F. (1934) curve for broadcast relay circuits.[6] Unless otherwise stated, all signal levels refer to the open-circuit voltage from a 75-ohm source.

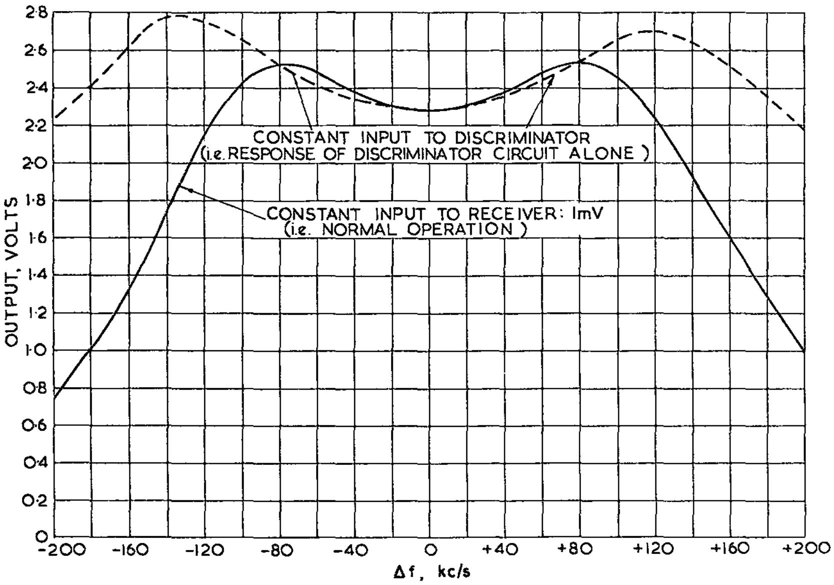


Fig. 9 - Tuning indicator response when driven from discriminator

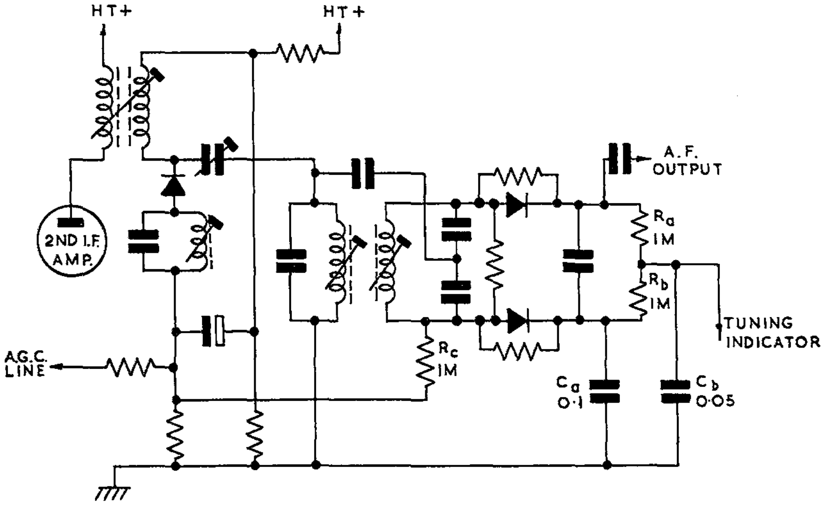


Fig. 10 - Circuit modifications to obtain tuning indicator drive from combination of a.g.c. and discriminator voltages

3.1. Sensitivity

The sensitivity of the receiver is defined as the minimum amplitude of signal input which satisfies simultaneously the following tests, 3.1.1, 3.1.2 and 3.1.3.

The measured value was 10 μV.

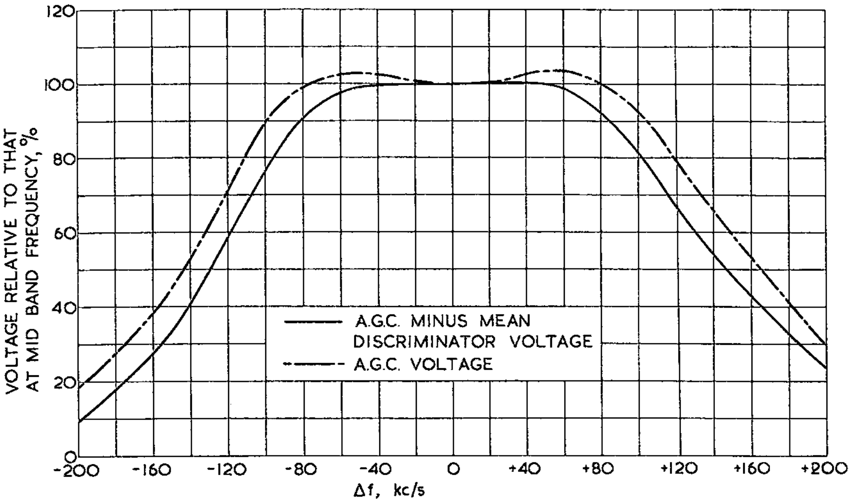


Fig. 11 - Tuning indicator response when driven from combined a.g.c. and discriminator voltage

3.1.1. Absolute Sensitivity

This is the minimum input signal amplitude, deviated ±35 kc/s at a frequency of 2000 c/s, which will produce an output of 50 mW with the receiver gain control at maximum.

The measured value was 8 μV.

3.1.2. Maximum Deviation Sensitivity for 10% Harmonic Distortion

This is the minimum input signal amplitude, deviated ±75 kc/s at a frequency of 400 c/s, which produces a total harmonic distortion of 10% or, if that figure is less than the input required to satisfy test 3.1.1, the distortion occurring at the input level required by test 3.1.1.

The distortion at 8 μV input level was 5%.

3.1.3. Sensitivity for Standard Signal-to-Noise Ratio

This is the minimum input signal amplitude, deviated ±35 kc/s at a frequency of 2000 c/s, which will produce an output signal-to-noise ratio of 40 dB.

The measured value was 10 μV.

3.1.4. Signal-to-Hum Ratio

An output signal-to-hum ratio of 40 dB was obtained when the input signal was deviated ±0·9 kc/s at 2000 c/s; a signal with a deviation of ±35 kc/s would therefore result in a signal-to-hum ratio of 72 dB.

3.2. Fidelity

3.2.1. Variation of Harmonic Distortion with Deviation

Fig. 12 shows the total harmonic distortion as a function of deviation with the receiver gain control set to give 50 mW output with ±30 kc/s deviation at 400 c/s. The input signal level was 10 mV.

3.2.2. Maximum Output Power for 10% Total Harmonic Distortion

The measured value was 1·5 watts.

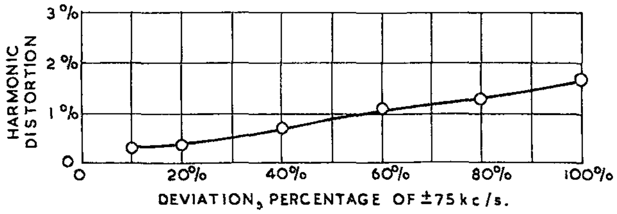


Fig. 12 - Variation of harmonic distortion with deviation

3.2.3. Modulation-Frequency Characteristic

This is shown in Fig. 13; the curve is corrected for a 50 μs pre-emphasis time constant.

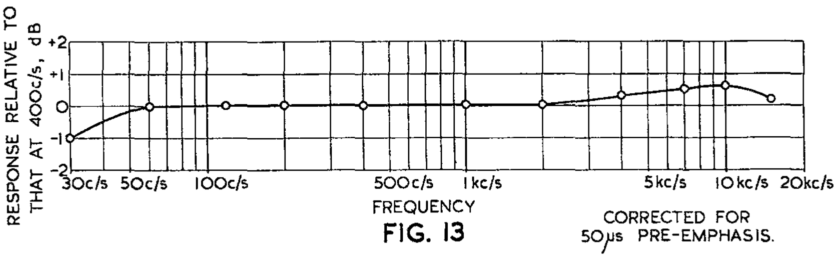


FIG. 13

Fig. 13 - Modulation-frequency response

3.3. Selectivity

The suppression ratio for an interfering signal is measured objectively as the ratio of unwanted-to-wanted signal amplitudes giving an output signal-to-interference ratio of 40 dB when the interfering signal is frequency modulated at 2000 c/s with a deviation of ± 35 kc/s.

The results for adjacent-, second- and third-channel interference (i.e. with 200, 400 and 600 kc/s frequency separations, respectively) are given in Table 1, together with the measured ratio for the image channel.

The wanted carrier level in each case was 1 mV.

TABLE 1

Frequency of unwanted carrier relative to wanted carrier	-21·4 Mc/s	-600 kc/s	-400 kc/s	-200 kc/s	+200 kc/s	+400 kc/s	+600 kc/s
Ratio of unwanted- to wanted-carrier levels (dB)	+28	>+40	+35	+6	+5	+34	>+40

For comparison with the figures in Table 1, the measured frequency response curves of the i.f. amplifier and discriminator are shown in Figs. 14 and 15.

3.4. Local-Oscillator Performance

3.4.1. Local-Oscillator Drift

The frequency variation of the local oscillator is shown in Fig. 16. Since the local-oscillator drift is comparable with that of the discriminator, a further curve is given showing the relative drift of local oscillator and discriminator, that is, the change of input signal frequency required to maintain zero d.c. output from the discriminator.

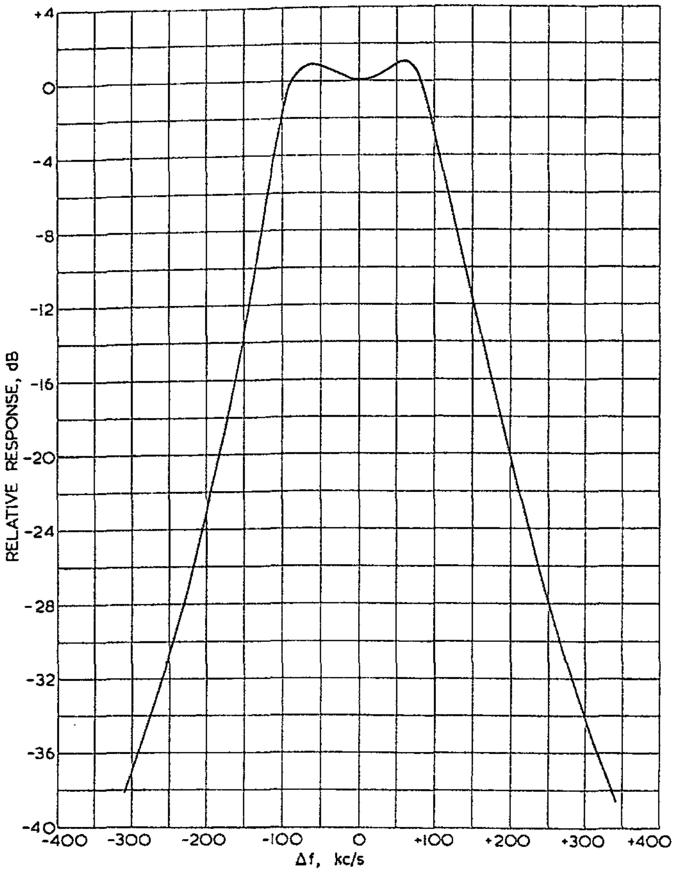


Fig. 14

I.F. amplifier frequency response

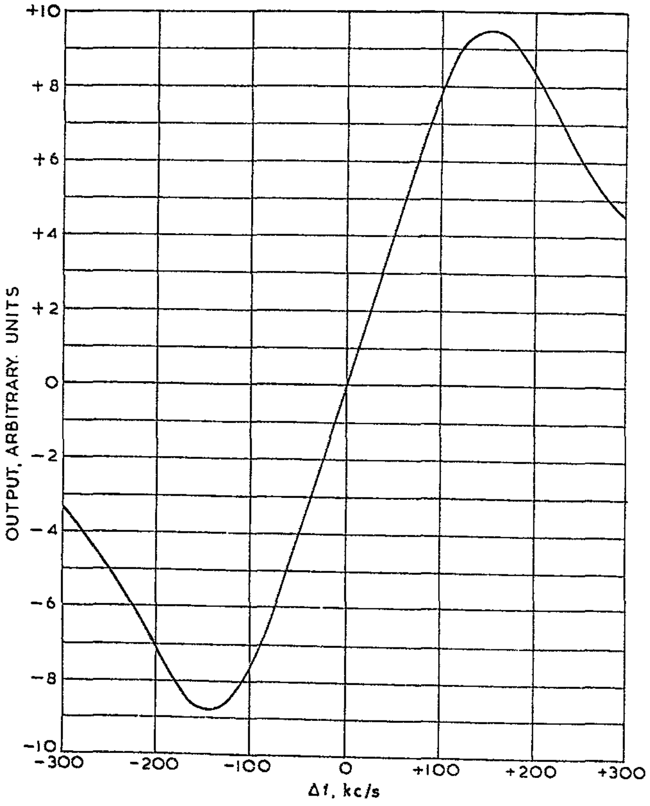


Fig. 15

Discriminator frequency response

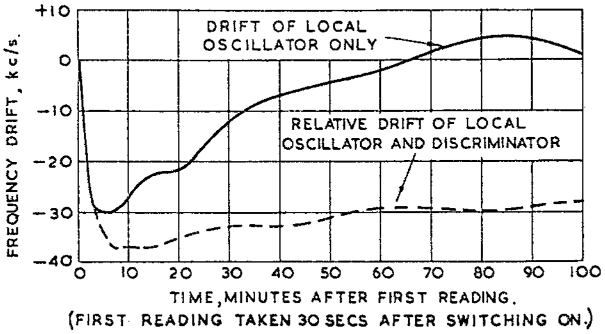


Fig. 16 - Local-oscillator frequency drift

3.4.2. Dependence of Local-Oscillator Frequency on Mains Voltage

The local oscillator frequency remained within ± 4 kc/s with a mains voltage variation of +20V to −30V.

3.4.3. Local-Oscillator Radiation

In this test the voltage at the input terminals of the receiver due to the local oscillator was measured, the input terminals being terminated in 75 ohms.

The measured voltage was 1·7 mV.

3.5. Co-Channel Suppression Ratio

As for test 3.3, but with the interfering signal frequency differing from the wanted signal by less than 1 kc/s.

The measured value was −6·5 dB.

3.6. Suppression of Amplitude Modulation

The a.m. suppression ratio is the ratio between the output due to a carrier which is frequency modulated ± 35 kc/s at 2000 c/s and that due to a carrier which is simultaneously amplitude modulated to a depth of 40% at 2000 c/s and frequency modulated ± 30 kc/s at 100 c/s, the 100 c/s output being rejected by a high-pass filter. The results for various input signal levels are shown in Table 2.

TABLE 2

Input signal level	A.M. suppression ratio
30 μV	35 dB
100 μV	38 dB
300 μV	41 dB
1 mV	43 dB
10 mV	48 dB
100 mV	49 dB

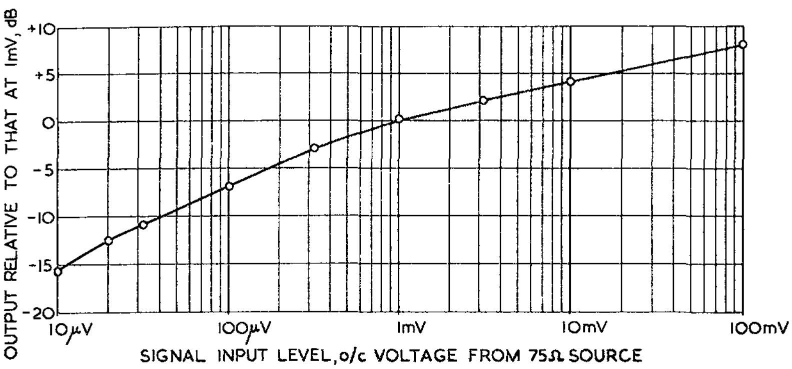


Fig. 17 - Variation of a.f. output with input level

3.7. Dependence of Output on Signal Level

This is shown in Fig. 17.

3.8. Impulsive Interference Performance

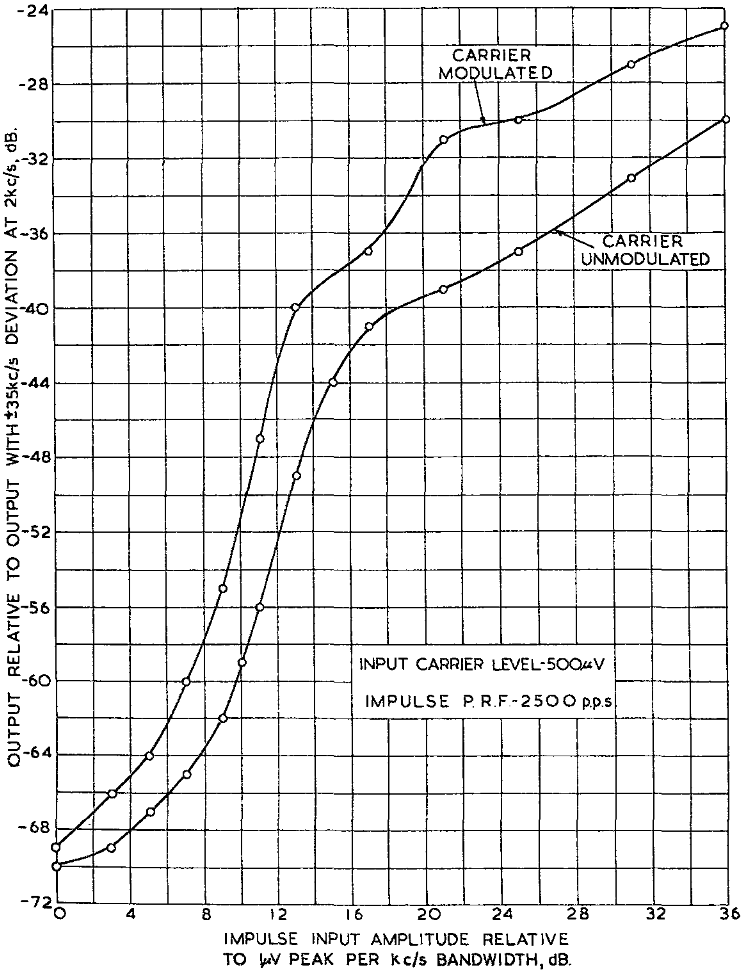


Fig. 18 - Input/output characteristic for impulsive interference

Fig. 18 shows the output due to impulsive interference, relative to that due to ±35 kc/s deviation at 2000 c/s, for various input impulse amplitudes.

The measurements were made in the presence of an input carrier of 500 μV, firstly unmodulated and secondly frequency modulated with ±30 kc/s deviation at 12 kc/s.

3.9. Subjective Measurements of Selectivity and Co-Channel Suppression Ratio

For these tests the receiver was fed with two signals, a wanted signal of 1 mV and an interfering signal of controllable amplitude which was set in turn to frequencies within 1 kc/s of, and spaced by ±200 kc/s and ±400 kc/s from, the wanted signal.

Both signals were frequency modulated with programme in accordance with standard B.B.C. transmitter practice, the wanted programme being speech and the interfering programme light orchestral music which gave a consistently high level of modulation. The amplitude of the interfering signal was adjusted to give the following subjective grades of interference:

JP The interference was just perceptible in the quiet passages of the wanted programme
P The interference was perceptible in quiet passages of the wanted programme without careful listening
SD The interference was slightly disturbing when listening to the wanted programme
D The interference was disturbing

The results given in Table 3 are the averages for four observers, the receiver having been tuned to give minimum output interference with the wanted and unwanted carrier within 1 kc/s, both unmodulated.

TABLE 3

Frequency of interfering signal relative to wanted signal (kc/s)		−400	−200	< +1 > −1	+200	+400
Amplitude of interfering signal relative to wanted signal (dB) to give the subjectives grades of interference	JP	+36·5	+4	−30·5	+6	+36·5
	P	+39	+5	−27	+7	+38·5
	SD	+40	+7	−22·5	+9	+40
	D	>+40	+9	−16·5	+11·5	>+40

The tests were repeated with the receiver mis-tuned both above and below the correct tuning point by an amount just less than that required to give audible distortion with speech programme. Table 4 shows the level of interfering signal required to give "perceptible" interference in these two conditions.

TABLE 4

Frequency of interfering signal relative to wanted signal (kc/s)		−400	−200	< +1 > −1	+200	+400
Amplitude of interfering signal relative to wanted signal (dB) to give 'P' interference with receiver mis-tuned as shown	mis-tuned high	> +40	+14	−25	−5	+28
	mis-tuned low	+28	−11	−25	+18	> +40

4. DISCUSSION OF RESULTS

The sensitivity of the receiver is regarded as adequate for domestic use. Signals below the level required for satisfactory operation are unlikely to be encountered within the service area of a transmitter unless the aerial is very inefficient or badly sited. In such cases improved reception is far more likely to be obtained with an improved aerial system than with increased receiver gain.

The selectivity more than meets the requirements of the planning standards for v.h.f. broadcasting in the United Kingdom, i.e. a protection ratio of 0 dB for adjacent channel signals.

The a.m. suppression ratio is maintained at or above the specified target figure of 35 dB down to an input level of $30 \mu V$. The a.g.c. is also operative over a similar range of input levels. While the constancy of output is not as good as that obtained with a static limiter, an input/output characteristic of the type shown in Fig. 17 does enable the user to select the local transmission by tuning to the loudest programme. With a static limiter the output level is independent of signal strength and it is possible, particularly in periods of abnormal tropospheric propagation, to tune inadvertently to a distant transmitter on an adjacent channel with consequent fading and poor quality.

The performance in respect of local oscillator frequency stability and radiation is somewhat below that which is obtained in some current commercial receivers. It could have been improved with further development time on the r.f. portion of the circuit, but this was regarded as a side issue since the design is primarily concerned with illustrating the potentialities of the limiter and discriminator circuit.

5. CONCLUSIONS

An economically designed receiver with a very satisfactory performance has been constructed. It employs a limiter and discriminator circuit which gives more efficient amplitude limiting than is generally obtained with a ratio detector, and in which the separation of the functions of limiting and frequency-to-amplitude conversion permits more flexibility in design.

6. REFERENCES

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